HOW DIRECTED ENERGY BENEFITS THE ARMY

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ABSTRACT

Directed energy, primarily through use of high-energy lasers (HELs), has already demonstrated significant capability to meet Army needs and current developments indicate there are future applications for HELs in numerous and varied mission areas. A HEL has already been used to clear minefields and the Tactical HEL (THEL) test bed has demonstrated kills of Rockets, Artillery and Mortars (RAM) that are responsible for causalities to US troops in current conflicts. HELs convert energy from chemical or electrical sources, for example, into intense, focused radiation that when directed onto targets will render them incapable of continuing their intended mission. There are multiple mechanisms for causing a kill. There are also multiple attributes of laser weapons, the majority of which are due to the intensity and speed-of-light transmission of the laser beam. There are a large number of HEL targets and applications in addition to those already indicated. These include, but are not limited to, reconnaissance and combat UAVs, cruise missiles, aircraft, battlefield optics/sensors, ballistic missiles, surface-to-air munitions, pop-up helicopters, and satellites. Specific Army HEL efforts include: (1) Mobile Tactical HEL (MTHEL) program, (2) the Airborne Tactical Laser Advanced Concept and Technology Demonstration (ACTD), and (3) the Zeus demonstration. HEL development programs are making significant advancements. With the fulfillment and implementation of these developments, HELs can provide a significant contribution to Army missions by providing broad capabilities. They can support force protection and enable the objective force to act first. HELs also can support precision strikes with minimal collateral damage. Significant progress has been made towards fielding HEL systems. A mine-clearing system, Zeus, has already seen action. The THEL ACTD made significant progress in weight and size reduction over earlier HELs, and demonstrated assured kills of RAM. The goal of the MTHEL program is to provide a mobile system more capable than THEL. Current technology programs are delivering products which will improve the fieldability of HEL weapon systems

1. INTRODUCTION

Directed energy systems transmit electromagnetic waves from a source to a target with the objective, in the case of directed energy weapons, of preventing the target from completing its mission. Directed energy can be generated and transmitted by high-energy lasers (HELs) and high power microwave systems. Army programs are primarily developing HELs, and consequently this paper will focus on HELs. This paper will present a background of the operation and characteristics of HELs followed by discussions of the application and benefits of HELs to the Army.

2. HEL OPERATION

HELs convert energy from chemical or electrical sources, among others, into intense, focused radiation that when directed onto targets will render them incapable of continuing their intended mission. There are two types of HELs in which Army development is being performed – chemical and solid state.

Chemical lasers use chemical reactions to excite molecules into a higher energy state so that the emission of laser radiation can occur. They have produced the highest average power ever observed with lasers. An example is the deuterium fluoride (DF) gas laser. The deuterium molecule (D_2) interacts with a fluorine atom to produce a DF molecule, a deuterium atom and energy. The energy released by the reaction serves to excite the DF molecule into a higher energy (excited) vibration level. The excited DF molecule will emit a photon of wavelength between 3.6 and 4.0 microns as it drops to a lower energy state. To provide the fluorine atoms, dissociation of the fluorine from its initial molecular state is accomplished by a thermal energy source.

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These concepts are implemented by flowing the fluorine molecules (F_2) with an inert gas carrier such as helium through a heater and mixing with D_2, injected through a multiple nozzle assembly. The chemical reaction of the gases occurs between the mirrors of the optical cavity where the laser beam is created and output perpendicular to the gas flow. A gas exhaust continues in the flow direction. The specific designs for Army chemical lasers, the Tactical High Energy Laser (THEL) and the Mobile THEL (MTHEL), are more complex, but follow this basic concept.

In solid state lasers, the lasing medium consists of a passive host crystal (or glass) in which an active impurity ion is added. The impurity ion is pumped to excited levels by a laser diode or a flash lamp. A challenge with solid state lasers is that as the lasing medium is cooled, thermal gradients are created that diminish the output power and degrade the wavefront quality of the beam resulting in higher divergence. This difficulty can be reduced by operating in a heat-capacity mode. In this mode the lasing is performed in rapid single shots without cooling (and the thermal beam distortions); after the thermal population of the lower laser energy level rises to significantly diminish the output, the pump source is shut down and then the temperature begins to drop. The laser will emit high power through a high pulse rate with a laser diode pump source, but can be rapidly cooled down by having the active ion in a crystal with high thermal diffusivity and large emission cross section. It was shown possible to have a near-continuous mode of operation by cooling laser slabs remotely and swapping the hot slab for a cooled one. Also, good beam quality can be obtained using an intracavity deformable mirror (Ritter et al., 2004).

3. HEL KILL MECHANISMS

Laser intensity, aim point, and lasing duration can be adjusted in order to defeat targets in different ways, and according to different mission scenarios. Some examples of these methodologies are:

(1) Rapid cook-off - An explosive target is sufficiently heated to cause the explosive to detonate.
(2) Structural Damage - Target structure, for example aerodynamic surfaces or target body, are damaged or destroyed such that the target is deflected, it aborts, or it disintegrates.
(3) Damage to guidance systems that cause the trajectory to divert.
(4) Damage to sensor systems or components.

4. HEL ATTRIBUTES

Specific attributes of laser weapons include:
(1) Intense lethal energy placed on the target - A HEL can melt a 1 square cm by 0.2-inch thick aluminum plate in about 1.4 sec.
(2) Negligible time-of-flight - Laser beams reach targets at the speed of light (about 300,000 kilometers per second). A HEL beam can travel great distances almost instantaneously and is not affected by gravity or atmospheric drag. Complex calculations determining ballistic trajectories of conventional weapons are not needed. Consequently, the challenge of tracking and intercepting a target is greatly simplified.
(3) Precision - Given a tracking mechanism with adequate accuracy, the inherent directional precision of a laser beam offers the HEL weapons system operator the capability to strike specific parts of fast-moving targets.
(3) Rapid retargeting – With the negligible time of flight and given efficient pointing/tracking systems, a HEL system can rapidly engage multiple targets. Retargeting, engagement, and defeat of multiple salvos of ballistic targets have been demonstrated.
(4) Low cost of a lethal round – Although the HEL system may initially be expensive to build and maintain, the cost per shot is low since the system primarily expends energy through its pumping activity or relatively inexpensive chemicals. The cost is only a few thousand dollars per shot while a certain interceptors can cost millions of dollars.
(5) Ability to react to time-critical targets - The negligible time of flight and efficient point/tracking systems provide capability to engage targets that have short launch to impact flight times. Some of these targets, such as electro-optical and infrared sensors or certain precision munitions, can be negated instantaneously.

5. HEL TARGETS/APPLICATIONS

HEL kill mechanisms and the attributes of HEL systems make possible the defeat of a wide array of targets, although in many cases the capability has yet to be fully explored and tested. These include, but are not limited to, reconnaissance and combat Unmanned Arial Vehicles (UAVs), cruise missiles, aircraft, battlefield optics and sensors, and ballistic missiles. In the case of the latter, boost-phase intercept would pose a threat to the launch area. In a Homeland Security role, surface-to-air missile defense around airports may be possible. Pop-up helicopters on the battlefield could be countered by HEL weapons systems due to their fast slew rate and practically zero time-of-flight, allowing negation while the helicopter is exposed. Satellites are vulnerable to

negation and defeat by HEL systems quite possibly without resultant space debris.

The Army is working to more fully develop HEL systems. The Mobile Tactical HEL (MTHEL) program will build and test a prototype that will destroy RAM and UAVs by 2008. In support of that program, the THEL test bed is being used to explore the capability to destroy different RAM targets in flight and has been successful against a wide array of targets already. The Airborne Tactical Laser (ATL) ACTD may perform the same mission currently answered by conventional airborne guns and short-range missiles, and the Zeus demonstrator destroys unexploded ordnance and clears minefields. A conceptual picture of MTHEL is presented in Figure 1 and a picture of Zeus is in Figure 2.

Further discussion of these targets, applications and programs is presented in section 6.

Figure 1: Mobile THEL

6. HEL CONTRIBUTION TO ARMY MISSIONS

HEL development programs are making significant advancements. With the fulfillment and implementation of these developments, HELs can provide a significant contribution to Army missions by providing broad capabilities.

In the near term, the Army's MTHEL program is designed for active defense against short-range threats such as battlefield rockets, artillery shells and mortars. The MTHEL program is part of the Army program intended to develop a multi-platform, multi-mission directed energy system for deployment as part of the Objective Force (Defense Science Board, 2001). The THEL Advanced Concept and Technology Demonstration (ACTD) resulted in the development of a transportable, ground-based laser weapon system with the capability to intercept multiple RAM targets in flight. The THEL has conducted more than 35 successful intercepts. Recently the THEL test bed killed artillery rounds in three separate live demonstrations and also performed kills of both an artillery shell and a rocket in which the capability to shift from one target to another using the same software was demonstrated. In addition to rockets and artillery, in a recent test the tracking and kill of mortar rounds, both singly and in salvos, was demonstrated. A directed-energy system such as THEL appears to be a viable means by which the Army's requirement for active defense against the short time-of-

Figure 2: Zeus

flight threat of rockets, artillery and mortars (RAMs) can be met (Schwartz et al, 2001).

The addition of a tactical directed-energy system to the Army's inventory of defenses against RAM threats could significantly impact ground force operations. Rocket, artillery and mortar threats have proven to be among the most difficult for the U.S. and coalition forces to defeat. In Operation Iraqi Freedom (OIF), hundreds of rounds of RAM are observed every day. Defeat of the small, fast, short time-of-flight RAM is beyond capabilities of conventional air defense. It is often difficult to identify the launch locations for these threats in order to conduct counter-battery fires and in many cases, counter-battery fire would put at risk civilian lives and structures. The threat posed by hostile fire could increase substantially as adversaries acquire advanced precision munitions, particularly those with anti-armor capability. Faced with such a threat, active defenses become all the more important (Thompson and Goure, 2002).

MTHEL could protect against the kind of rocket and mortar threats that U.S. troops have been facing in Iraq and Afghanistan (Spenser and Carafano, 2004). An

MTHEL prototype is planned for 2008 which will be used to conduct developmental testing, as well as gain insight into the tactics, techniques, procedures, employment options, and HEL defensive effectiveness in combat situations necessary in order to transition the prototype to a fully-capable weapons system. This effort will also support the development of future requirements for sensors that could support HELs, such as radar, laser radars, laser illuminators, or infrared sensors.

An advanced version of the THEL system could be employed against a range of air-breathing threats such as ground attack aircraft, helicopters, unmanned aerial vehicles (UAVs) and cruise missiles (Garner, 2002). Other countries are investing in UAVs for intelligence, surveillance, and reconnaissance (ISR) and strike purposes. The importance of efforts to deny adversaries ISR information will grow as the US Army transforms itself into a lighter, more agile force and the survivability of that force will depend, in part, on a combination of mobility and information dominance. HEL weapons systems support the counter-ISR capability that will take on an increasingly prominent role in future Army operations. Directed-energy systems could play a critical role in meeting the requirements of the counter-ISR mission (Garner, 2002; Thompson and Goure, 2002).

For emerging roles and missions, the Airborne Tactical Laser (ATL) could be a platform independent system deployed on a ground vehicle, tactical aircraft (as depicted in Figure 2) or rotorcraft. The ATL would perform a number of missions including precision target engagement and high-resolution imagery for target identification (Defense Science Board, 2001). An ATL could also provide an aerial defense against cruise missiles and a means of counter-battery fire against RAM. It has also been suggested that because of its high precision and lack of signatures when fired, the ATL would be an excellent long-range precision strike system for Special Operations Forces or for ground forces operation in an urban environment (Thompson and Goure, 2002).

In the Army's future Objective Force, directed energy weapons could become a critical element. Central to the creation of the Objective Force is the Future Combat System (FCS). The FCS is envisioned as a "system-of-systems" employing both manned and unmanned ground and aerial vehicles equipped with a wide range of weapons, including directed energy. Batteries of mobile vehicles that separately contain battle management, command, control, computers and intelligence, sensor and HEL equipment as part of a system of systems could be positioned or advance on the battlefield to detect, communicate, and defeat RAM, UAVs, aircraft, and cruise missile threats and clear mines. One asset in the inclusion of directed energy weapons is that they may

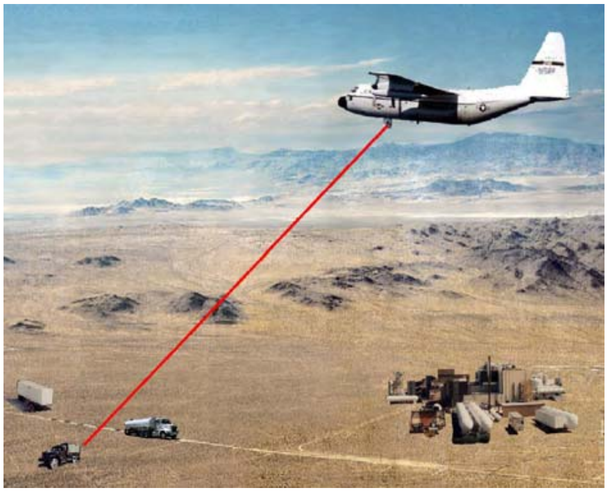

Figure 2: ATL Mission

significantly reduce the logistics burden on the Objective Force. The FCS could employ directed energy weapons for counter-surveillance, air defense and mine clearance. Directed-energy weapons could be deployed across the full range of manned and unmanned FCS platforms (Thompson and Goure, 2002).

CONCLUSION

Significant progress has been made towards fielding HEL systems. A mine-clearing system has already seen action. The THEL ACTD made significant progress in weight and size reduction of chemical lasers and the resulting THEL test bed has demonstrated assured kills of RAM. The goal of the MTHEL program is to provide a mobile system more capable than THEL by 2008. Current technology programs are delivering products that will improve the fieldability of HEL weapon systems.

In summary, the development and fielding of HEL weapon systems will provide the capability to kill RAM threats, a leading cause of battlefield casualties in OIF, and will enhance the capability to defeat a wide variety of other threats to US personnel. Further development of HEL systems can provide capability to deny adversaries ISR information, provide capability for long-range precision strikes, and become a valuable asset to the Future Combat System. The current development program results and the potential capabilities indicate that HELs are of significant benefit to the Army.

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